ILC R&D at Fermilab Overview

(Main Linac and Superconducting RF)

Shekhar Mishra

Fermilab

Charge

- Review the goals of the ILC component of SMTF.
  - As presented do the elements form the basis of a program which will allow the U.S. to establish the technical capabilities in SCRF required to support a bid to host the ILC?
- Consider the following areas and offer comment as appropriate:
  - The "deliverables" that the ILC GDE can expect to receive from this program and their projected influence on the ILC design and/or preparations for construction.
  - The strategic approach outlined for cryomodule production and testing in view of the existing capabilities within the national laboratories and universities, and the adequacy of the proposed supporting infrastructure and resources.
  - The relationship between the SMTF plan and a more comprehensive U.S. industrialization plan in support of ILC construction.
  - The role of the photo-injector and its upgrades within the ILC program.

Establish U.S. Technical Capabilities In SCRF

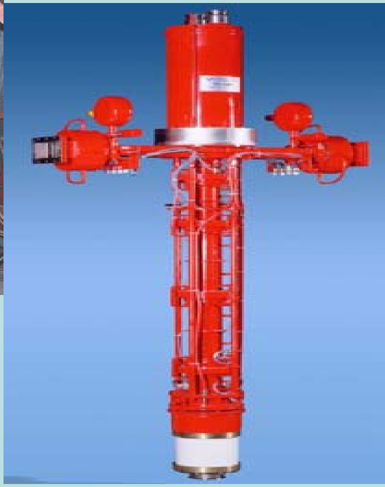
- Deliverable
  - Cavity technology to achieve 35 MV/m
  - Fully tested basic building blocks of the Main ILC Linac
  - ILC Cryomodule design
- Strategic Approach
  - Cavity fabrication using industry and existing infrastructure at collaborating laboratories.
  - Improve and Build infrastructure at Fermilab
  - Horizontal test, string assembly and cryomodule fabrication at Fermilab
- Industrialization Plan

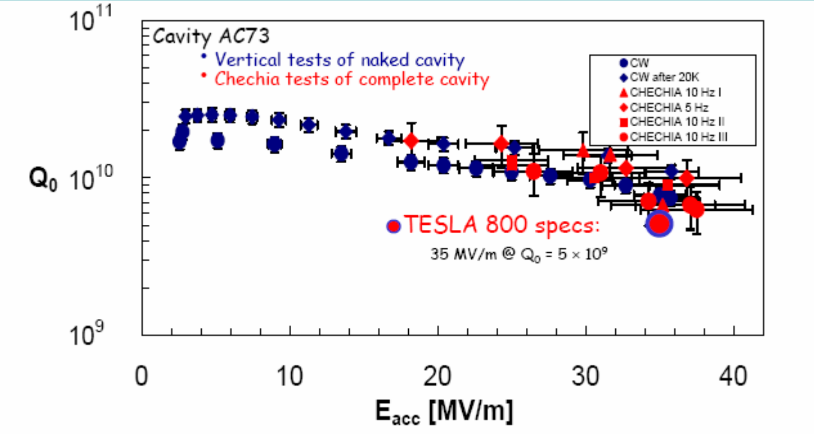
International Capability: DESY

Cavity fabrication & processing to cryomodule fabrication, testing and beam studies at TTF

Modulator

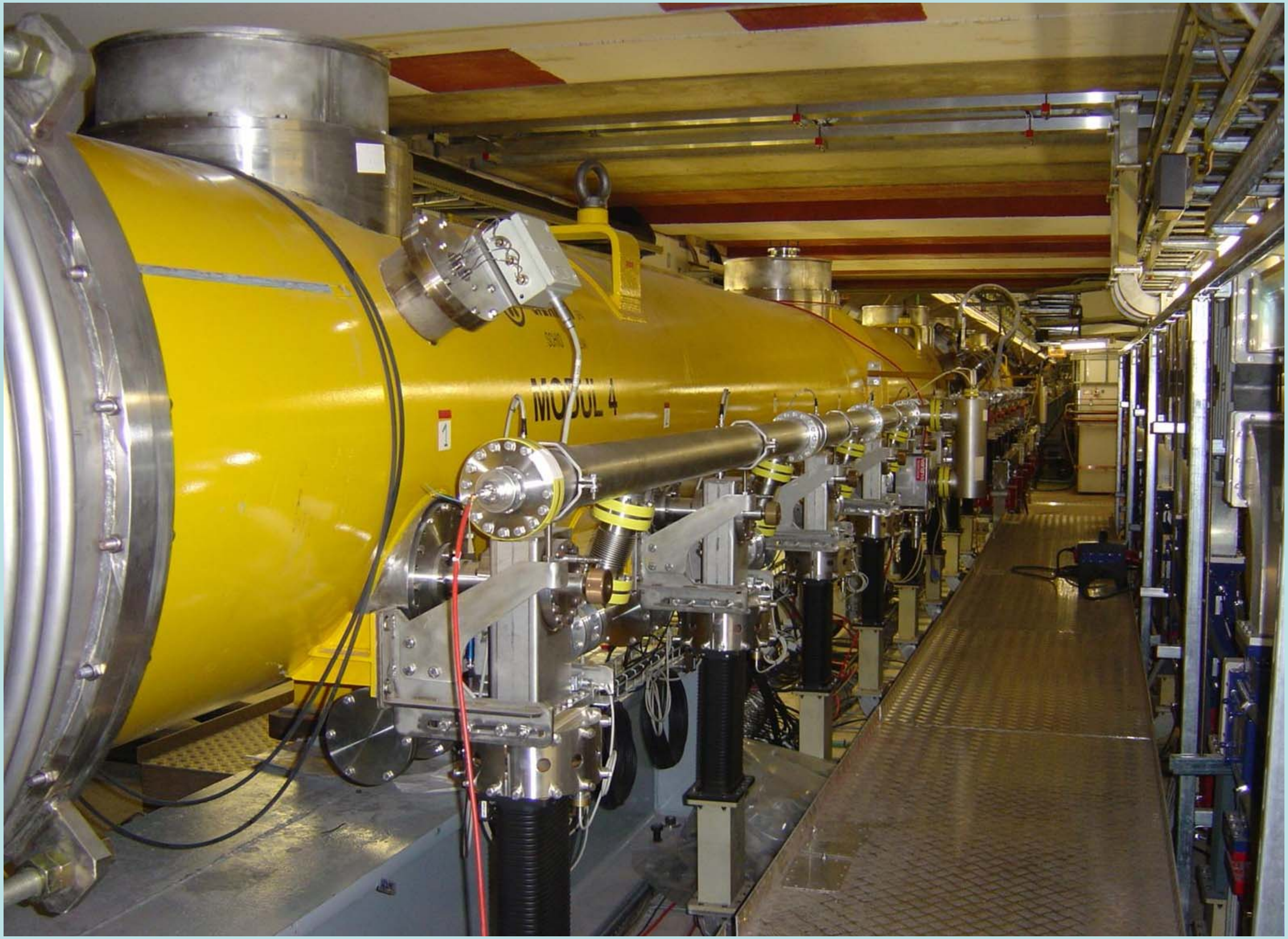
Klystron





Cavity Performance

Cryomodules at DESY TTF



TTF/VUV-FEL Schedule 2005

	week	dates		conferences
January	1	03.01. - 09.01.	VUV FEL commissioning, 30 nm, single bunch	
	2	10.01. - 16.01.		
	3	17.01. - 23.01.		
	4	24.01. - 30.01.		
February	5	31.01. - 06.02.	VUV FEL commissioning, 30 nm, single bunch	
	6	07.02. - 13.02.	continue and get saturation	
	7	14.02. - 20.02.		
	8	21.02. - 27.02.	FEL Studies, evtl. incl. reaching shortest wavelengths	
March	9	28.02. - 06.03.	Shutdown for installation of beamline components into the tunnel and interlock tests	
	10	07.03. - 13.03.	work on modulators?	
	11	14.03. - 20.03.		
	12	21.03. - 27.03.	FEL Studies, evtl. incl. reaching shortest wavelengths	
April	13	28.03. - 03.04.		
	14	04.04. - 10.04.	Commissioning of beamlines: 2 Shifts per day	
	15	11.04. - 17.04.	including first tests of diagnostics: HASYLAB	
	16	18.04. - 24.04.	II-02-048 FEL, M. Richter and II-02-037 FEL, M. Meyer	Zeuthen
	17	25.04. - 01.05.	3rd shift for FEL studies	
May	18	02.05. - 08.05.	FEL studies	
	19	09.05. - 15.05.	II-02-052 FEL, W. Wurth and II-02-048 FEL, M. Richter	
	20	16.05. - 22.05.	P. Zeitoun: I3-JRA2 and II-02-042 FEL	PAC 2005
	21	23.05. - 29.05.	LLRF studies at moderate gradients	
June	22	30.05. - 05.06.		
	23	06.06. - 12.06.	Maintenance incl. MBK + addl. Klystron/Modulator (Choroba)	DIPAC
	24	13.06. - 19.06.		
	25	20.06. - 26.06.	II-02-052 FEL, W. Wurth and II-02-050 FEL, A. Wolf	
	26	27.06. - 03.07.	II-02-037 FEL, M. Meyer and II-02-047 FEL, K.-H. Meiwes-Broer	Ferienzeit
July	27	04.07. - 10.07.	High gradient studies incl. Cryo and LLRF	Ferienzeit
	28	11.07. - 17.07.		Ferienzeit
	29	18.07. - 24.07.	Accelerator Studies (e.g. HOM studies cav. alignment)	Ferienzeit
	30	25.07. - 31.07.	FEL studies	Ferienzeit
August	31	01.08. - 07.08.	II-02-050 FEL, A. Wolf and II-02-051 FEL, U. Becker and II-02-052 FEL, T. Möller	Ferienzeit
	32	08.08. - 14.08.		Ferienzeit
	33	15.08. - 21.08.	II-02-049 FEL, R. Lee, R. Fedosejevs and II-02-039 FEL, J. Hajdu, H. Chapman and II-02-042	Snowmass
	34	22.08. - 28.08.	FEL, M. Drescher	FEL/Snowmass
September	35	29.08. - 04.09.	LLRF Studies	
	36	05.09. - 11.09.		
	37	12.09. - 18.09.	Maintenance e.g. modulators	
	38	19.09. - 25.09.		
	39	26.09. - 02.10.	Accelerator Studies (to be defined)	
October	40	03.10. - 09.10.	II-02-054 FEL, K. Starke and II-02-044 FEL, L. Kipp	
	41	10.10. - 16.10.	II-02-043 FEL, M. Kirm	
	42	17.10. - 23.10.	II-02-049 FEL, R. Lee, K. Sokolowski-Tinten and II-02-049 FEL, R. Lee, P. Zeitoun	
	43	24.10. - 30.10.	II-02-047 FEL, K.-H. Meiwes-Broer	
November	44	31.10. - 06.11.	LLRF (high gradients)	
	45	07.11. - 13.11.		
	46	14.11. - 20.11.	Accelerator studies (full beam loading)	
	47	21.11. - 27.11.	II-02-045 FEL, J.R. Crespo Lopez-Urrutia	
December	48	28.11. - 04.12.	II-02-046 FEL, J. Ullrich, Moshammer	
	49	05.12. - 11.12.	II-02-041 FEL, H. Zacharias	
	50	12.12. - 18.12.		
	51	19.12. - 25.12.	Accelerator studies (full beam loading)	
	52	26.12. - 01.01.	Maintenance	

FEL studies	13 weeks	*normal* weeks might not include the maintenance day (Tuesday), i.e. each week has 18 shifts only
User operation	19 weeks	
accelerator studies	12 weeks	
maintenance	8 weeks + 44 days	

adjust schedule???

TTF is focusing on:

VUV/FEL Studies
User Operation
LLRF Development

TESLA Technology Collaboration

TTF: VUV/FEL (Operation)
XFEL (28 MV/m)
ILC (35 MV/m)

ILC-TRC Ranking

- The ILC-TRC Second report outlined the R&D needed for the ILC for its importance and urgency.
  - Ranking 1: R&D needed for feasibility demonstration of the machine.
  - Ranking 2: R&D needed to finalize design choices and ensure reliability of the machine.
  - Ranking 3: R&D needed before production of systems and components.
  - Ranking 4: R&D desirable for technical or cost optimization
- US Linear Collider Technology Option Study expanded this study by the reliability and risk analysis.
- These R&D goals will guide the SMTF programs.

Ranking 1: Energy

- The feasibility demonstration for the ILC requires that a cryomodule be assembled and tested at the design gradient of 35 MV/m.
- This test should prove that quench rates and breakdowns, including couplers, are commensurate with the operational expectations.
- It should also show that dark currents at the design gradient are manageable, which means several cavities should be assembled together in a cryomodule.

To date no Cryomodule in the world exists that can satisfy these. ILC will need several to have confidence.

DESY X-FEL will focus on ~28 MV/m.

DESY TTF-II has multiple priorities and may not be able to carry out the long-term tests necessary at 35 MV/m for ILC.

Ranking 2: Energy

- To finalize the design choices and evaluate the reliability issues it is important to fully test the basic building block of the linac.
  - This means several cryomodules installed in their future machine environment, with all auxiliaries running, like pumps, controls etc.
  - This test should as much as possible simulate the realistic machine operating conditions, with the proposed klystron, power distribution system and with beam.
  - The cavities must be equipped with their final HOM couplers.
  - The cavity relative alignment must be shown to be within requirements.
  - The cryomodules must be run at or above their nominal field for long enough periods to realistically evaluate their quench and breakdown rates.

- DESY has been leading this effort but the focus of TTF is now on operation with limited beam time for ILC related studies and development.

- X-FEL R&D may not be able the answer to all these ILC questions.

- ILC R&D needs to focus on these. These are the goals of SMTF.

Technology Studies: ILC-WG 2 & 5 (ILC Workshop at KEK)

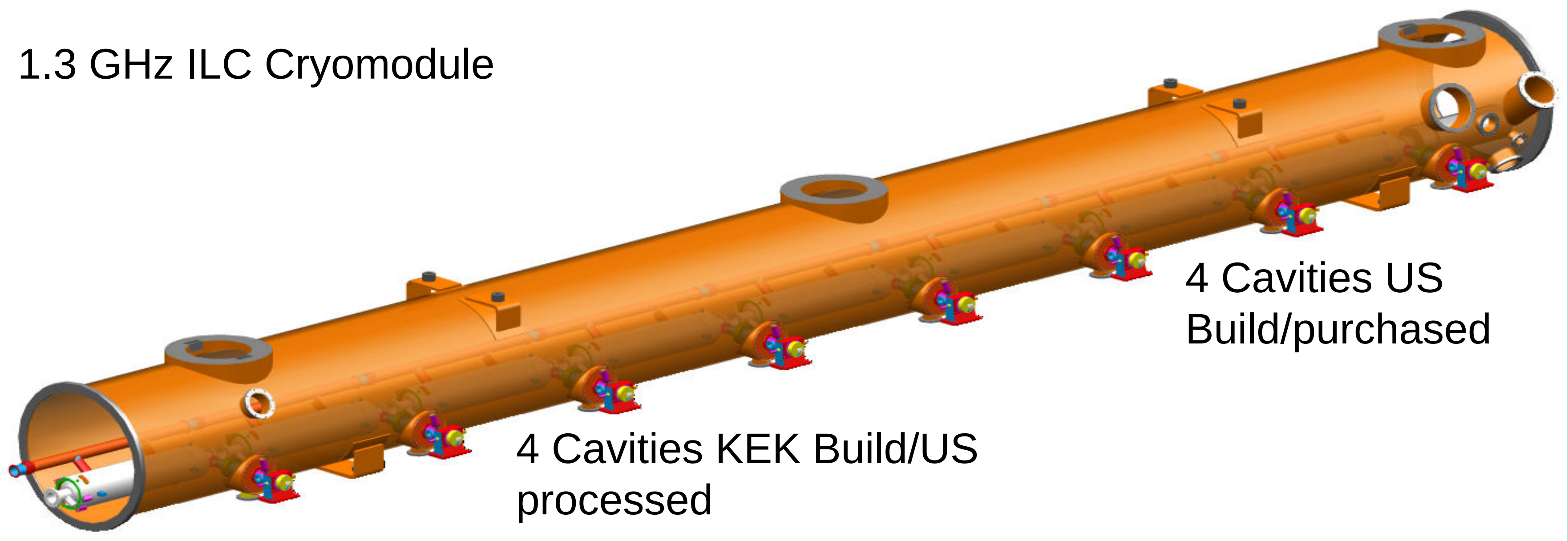
- Determine the maximum operating gradient of each cavity & its limitations.
- Evaluate gradient spread and its operational implications.
- Measure dark currents, cryogenic load, dark current propagation, and radiation levels.
- Measure system trip rates and recovery times to assess availability.
- Evaluate failures with long recovery times: vacuum, tuners, piezo controllers, and couplers.
- Develop LLRF system, exception handling software to automate system and reduce downtime.
- Measure alignment of the quadrupole, cavities and BPM in-situ using conventional techniques (e.g. wire or optical).
- Measure vibration spectra of the cryomodule components, especially the quadrupole magnet.

Superconducting RF Module & Test Facility (SMTF)

Main Goal: Develop U.S. Capabilities in fabricating and operating with Beam

High gradient (35 MV/m or Greater) and high Q (~0.5-1e10)

Superconducting accelerating cavities and cryomodule in support of the International Linear Collider.



SMTF Collaborating Institute and their representative

- Argonne National Laboratory: *Kwang-Je Kim*
- Brookhaven National Laboratory: *Ilan Ben-Zvi*
- Center of Advanced Technology, India: *Vinod Sahni* *(More institutions have asked to join)*
- Cornell University: *Hasan Padamsee*
- DESY: *Deiter Trines*
- Fermi National Accelerator Laboratory: *Robert Kephart*
- INFN, Pisa : *Giorgio Belletini*
- INFN, Frascati: *Sergio Bertolucci*
- INFN, Milano: *Carlo Pagani*
- Illinois Institute of Technology: *Chris White*
- KEK: *Nobu Toge*
- Lawrence Berkeley National Laboratory: *John Byrd*
- Los Alamos National Laboratory: J. *Patrick Kelley*
- Massachusetts Institute of Technology: *Townsend Zwart*
- Michigan State University: *Terry Grimm*
- Northern Illinois University: *Court Bohn*
- Oak Ridge National Laboratory: *Stuart Henderson*
- Stanford Linear Accelerator Center: *Chris Adolphsen*
- Thomas Jefferson National Accelerator Facility: *Swapan Chattopadhaya*
- University of Pennsylvania: *Nigel Lockyer*
- University of Rochester: Adrian Melissinos

Proposal was submitted to Fermilab on Feb. 18th 2005.

Interactions with DOE and GDE

Most of these institutions have joined with ILC R&D interest.

ILC needs this collaborations technical ability to succeed.

US-ILC Main Linac Responsibilities

- ILC Studies will be coordinated with GDE.

- In US Fermilab has the responsibility of the Main Linac superconducting part and RF Control.
  - We are coordinating this work with the collaborating institutions.

- In US SLAC has the responsibility of the Main Linac RF power.
  - We are developing modulator and purchasing klystron to get started based on existing design.
  - SLAC is doing R&D and will be taking a lead in this for ILC.

ILC R&D Goals

- Develop the capability to reliably fabricate high gradient and high-Q SCRF cavities in U.S. ($\geq$ 35 MV/m and ~0.5-1e10)
- Establish a R&D capacity infrastructure for the assembly of cryomodules at Fermilab.
- Fabricate 1.3 GHz high gradient cryomodules. Test cryomodules (2 deg K) and RF power components. Iterate design as fabrication and operational experience is acquired and designs are optimized.
- Establish a high gradient, 1.3 GHz cryomodule test area at Fermilab with a high quality pulsed electron beam using an upgraded A0 photo-injector.
- Demonstrate 1.3 GHz cavity operation at 35 MV/m with beam currents up to 10 mA at a ½ % duty factor. Higher currents or duty factors may be explored if the need arises.
- Investigate cost reduction strategies.

1.3 GHz Cavity Fabrication

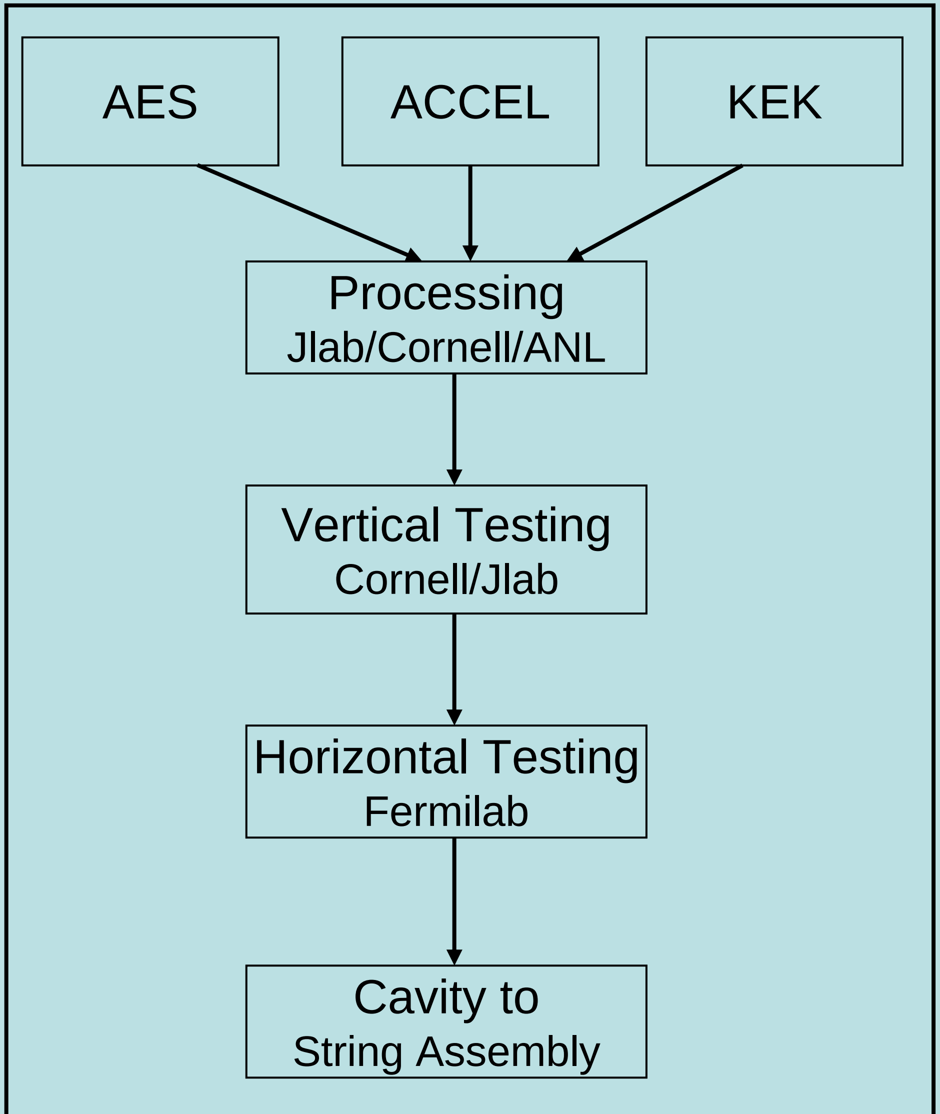
- We are converting all the DESY drawings in US system for US vendors.

- At present we plan to develop cavity in collaboration with Jlab, Cornell, ANL, SLAC and industries.

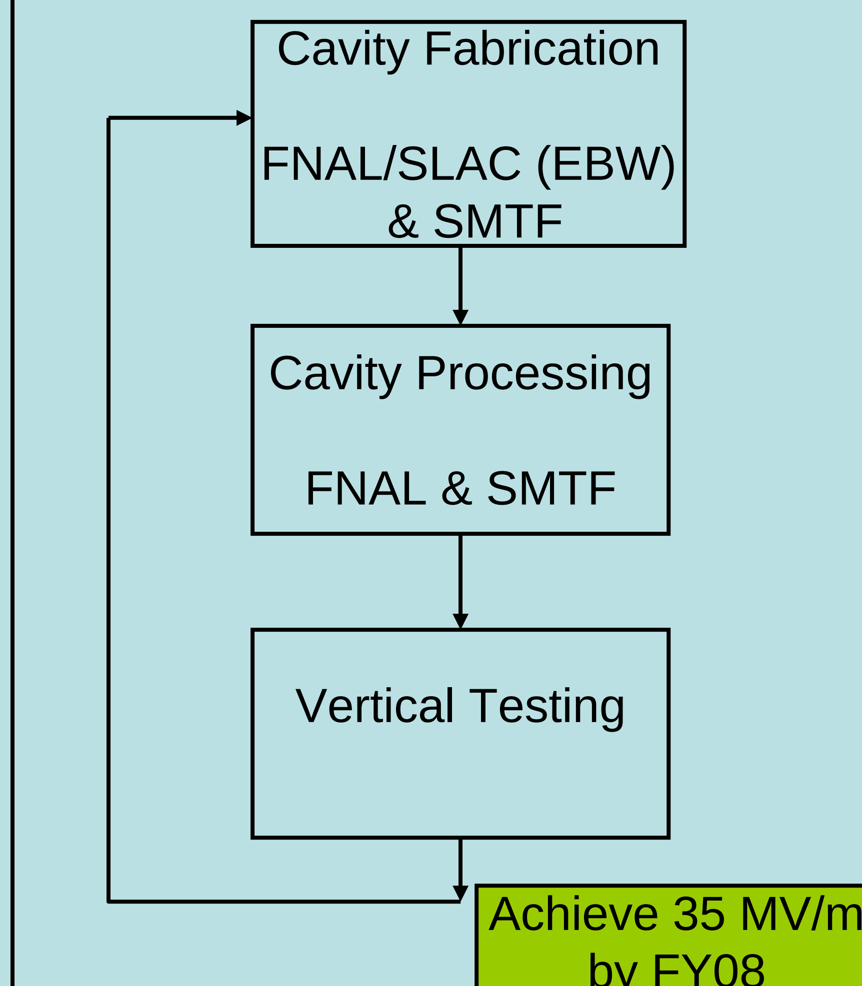
- In view of the ILC, we are developing plans for cavity fabrication. This would be driven by the need to master the cavity fabrication technology to achieve $\geq$ 35 MV/m. (Cavity fabrication ←→ Vertical testing)

<u>Deliverable:</u> Cavity fabrication technology to reliably and cost effectively produce cavities with gradient $\geq$ 35 MV/m. (FY08)

Cavity Fabrication



Perfecting the gradient technology



ILC Cryomodule

- We are developing infrastructure for cavity and cryomodule fabrication.
- The plan is to build the first US cryomodule which is a exact copy of TTF cryomodule (version 3+) (Ready by 06)
- Fermilab in collaboration with SLAC and DESY is making detailed Main Linac Low Emittance preservation simulation that will yield a new cavity alignment specification.
- There has been considerable discussion within ILC regarding the need to develop a 4th generation cryomodule.
  - Compact spacing of cavities and general length reduction
  - Quadrupole package at the center or as a separate unit
  - Number of cavities (8 vs 12)
  - Input coupler and processing improvements
- We are proposing to hold a ILC workshop on 4th generation cryomodule need and design.

<u>Deliverable:</u> ILC Cryomodule design. (FY09)

ILC Main Linac Simulation

Nominal Installation Conditions

Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 μm
Quad offset w.r.t. Cryostat	300 μm
Quad Rotation w.r.t. Cryostat	300 μrad
Structure Offset w.r.t. Cryostat	300 μm
Cryostat Offset w.r.t. Survey Line	200 μm
Structure Pitch w.r.t. Cryostat	300 μrad
Cryostat Pitch w.r.t. Survey Line	20 μrad
BPM Resolution	1.0 μm

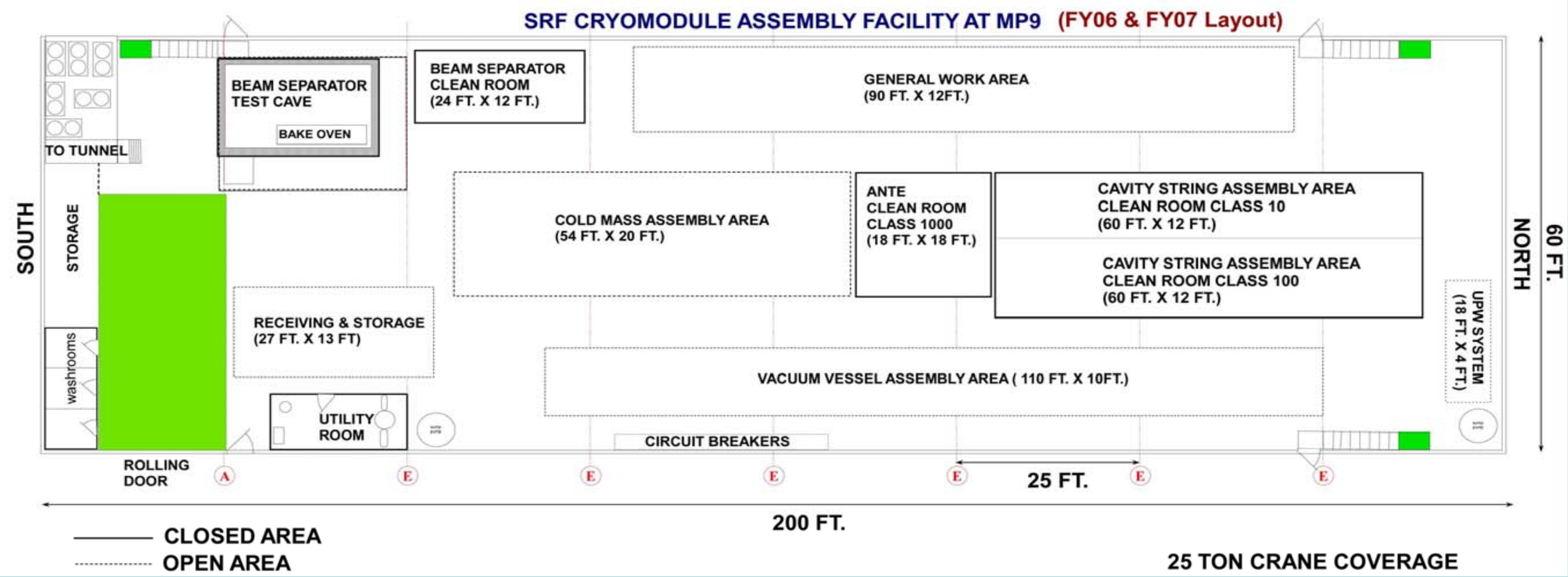
Not mentioned in TESLA TDR

10 μm in TDR,

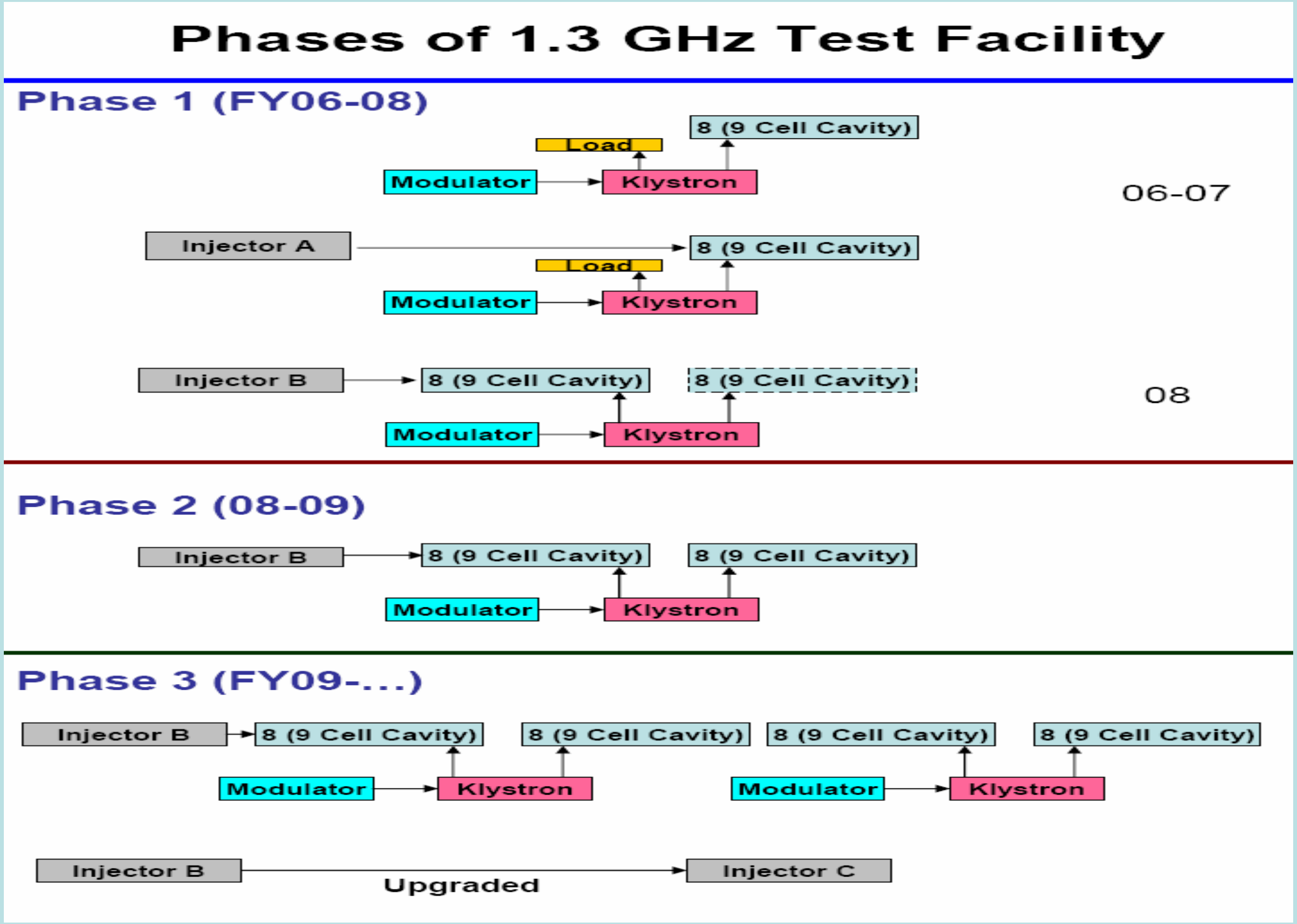
- Fermilab in collaboration with SLAC and DESY is carrying out a detailed Low Emittance Transport simulation for the Main Linac.
- These simulation will set the alignment and resolution requirements for the ILC components.
- These studies will also help evaluate different lattice configuration and quadrupole placement.

Cavity Testing And Cryomodule Fabrication

- Cavity is produced, processed and vertically tested at SMTF collaborating institutions and start-up US industries.
- Cavity is horizontally tested at Fermilab and assembled in string at MP9.
- Cryomodule fabrication takes place at MP9.
- Single cryomodule will be tested at the Meson Test Area.



Proposed ILC Cryomodule Fabrication and Beam Test at Schedule

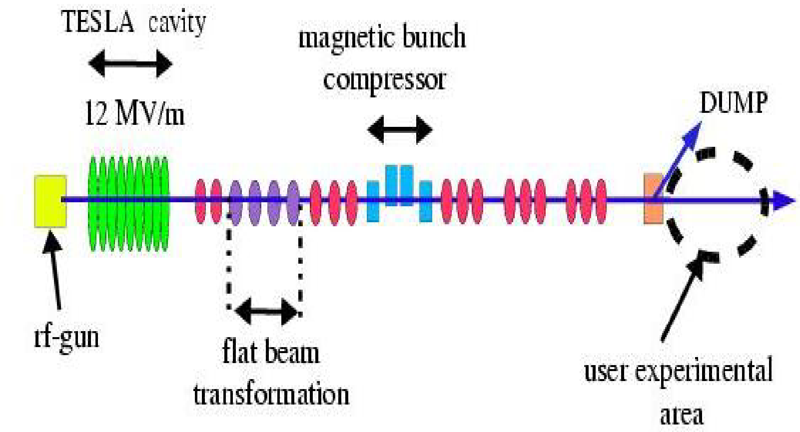


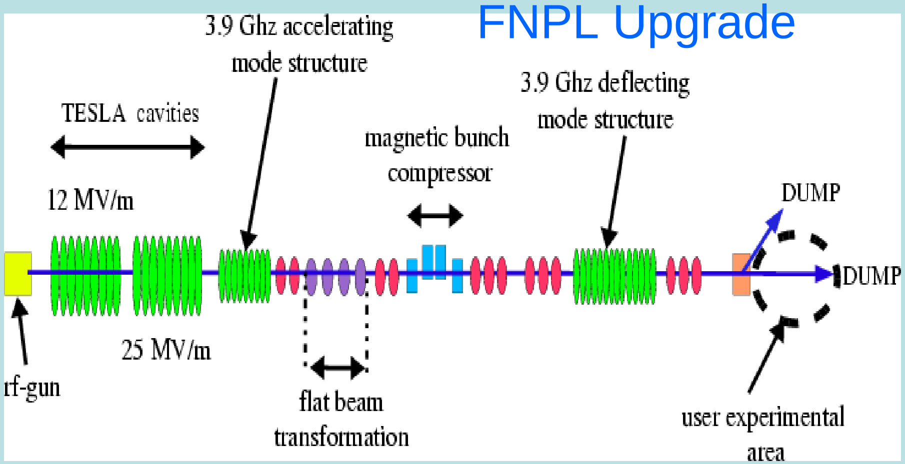
Year	Cryomodule Number
06	1
07	2
08	3
09	4-5
10	5-6

We are expecting that 4/6 will reach design gradient.

Deliverable: Fully tested basic building blocks of the Main ILC Linac.
Evaluate the reliability issues. Finalize design choices with GDE (FY09)

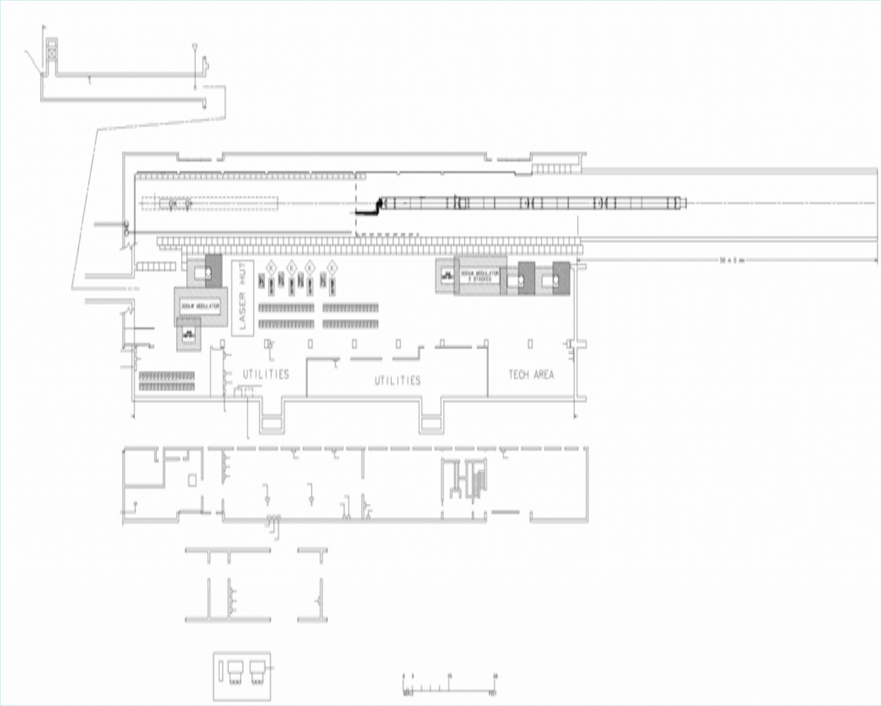
FNPL as Electron Beam source for ILC Test Area





		SMTF proposed (up to)	Present Inj typ
RF pulse length	msec	1.5	0.03-0.6
Pulse rate	Hz	5	1
Beam pulse length	msec	1.0	10-20 micro sec
Beam current	mA	15	10
Electrons per bunch	e10	2	0.6-6.0
Bunch spacing	ns	337	1000
Beam pulse*current	ms*mA	10	0.2

ILC Cryomodule Beam Testing at The New Muon Lab



- This is a new plan of setting up ILC test area in the New Muon Lab and will require some civil construction.
- This enable us to setup a single cryomodule test area in Meson and have enough room.
- The plan is being developed and will be described by Peter Limon.

RF Power, Controls and LLRF System

- Two modulators are being build at Fermilab. Klystron will be purchased from Industry.
- DESY prototype FPGA LLRF controller has been installed and tested at Fermilab.
- SMTF is collaborating with DESY on LLRF developments and study at TTF.
- Fermilab is designing and building a low noise master oscillator for the LLRF system.
- We are developing control algorithms and state control software.
- System design will include: Multiple cavities per klystron operation and Piezo tuner control

<u>Deliverable:</u> RF Controls and LLRF System for ILC

ILC Instrumentation

- A next generation ILC instrumentation will be needed to meet the low emittance preservation specification. (For example a better resolution BPM will be needed)
- The dedicated ILC beam test facility would provide opportunities to investigate different instrumentation ideas in a realistic environment.
- It can also help develop techniques on how to use the HOM position information in correlation with the BPM is aligning the beam to the cavities.

<u>Deliverable:</u> Instrumentation Development

US Industrial Interaction

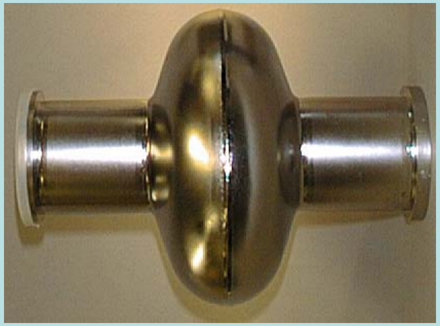
- US Industrial base need to enhance in both technology and infrastructure for ILC.
- We have started initial industrial contact for the cavity fabrication works.
  - AES (Small)
  - ACCEL (Mid-Size)
- We are working with local industry in fabricating parts for the cryomodule. (At present plan is to assemble at Fermilab)
- Parson has made a visit to Fermilab to learn about ILC. It expressed interest in learning about cavity and cryomodule fabrication.
- Development of the US Industrial forum for ILC is being discussed. We are planning to hold a workshop for industry.

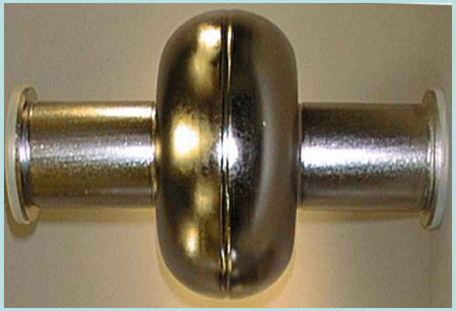
Technology Transfer: Industry

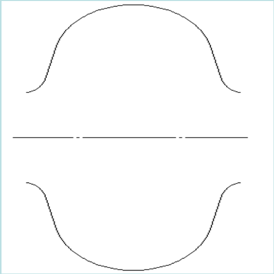
- In a MOU between Fermilab-Cornell we are purchasing 1.3 GHz cavities from AES. Several other MOU between collaborating institutes are in progress.
- The cavities will be fabricated by AES and chemically treated and vertically tested *by AES* using the Cornell facility.
- So far there is no industry in the world that has learned how to chemically prepare and vertically test the 9-cell cavity.
- These industrial initiatives will not be sufficient for the ILC production needs.
- We need to attract and train large industrial firms to increase the production capabilities by 2010. A industrialization plan is needed for ILC.

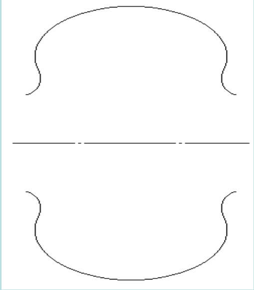
Deliverable: Cavity & Cryomodule Technology transfer to Industry.

Higher Gradient R&D: Re-entrant









Cornell Result R&D

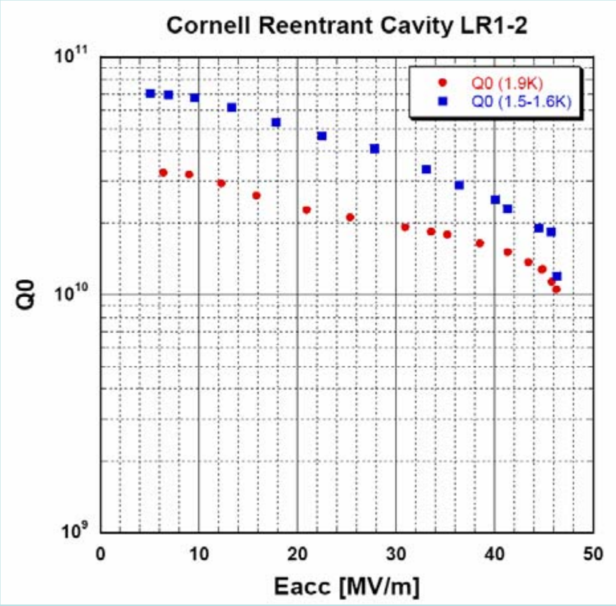
Single cell Nb cavity

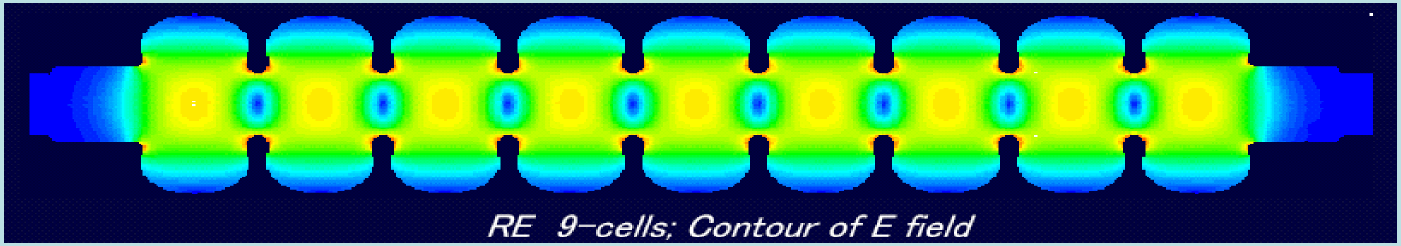
70 mm TESLA-like aperture

Achieved 46 MV/m at Q = 10^{10}

Hpk = 1755 Oersted

Epk = 100 MV/m





Fabricate 9-cell re-entrant structure

Same length as TESLA structure

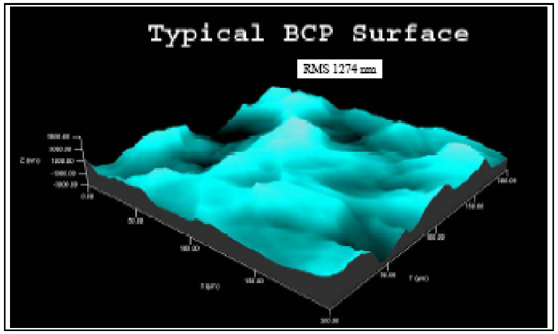
Chemical treatment, Vertical test

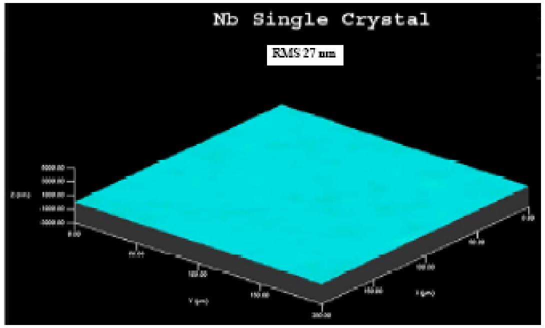
Goal Eacc > 40 MV/m

Higher Gradient R&D: Single Crystal

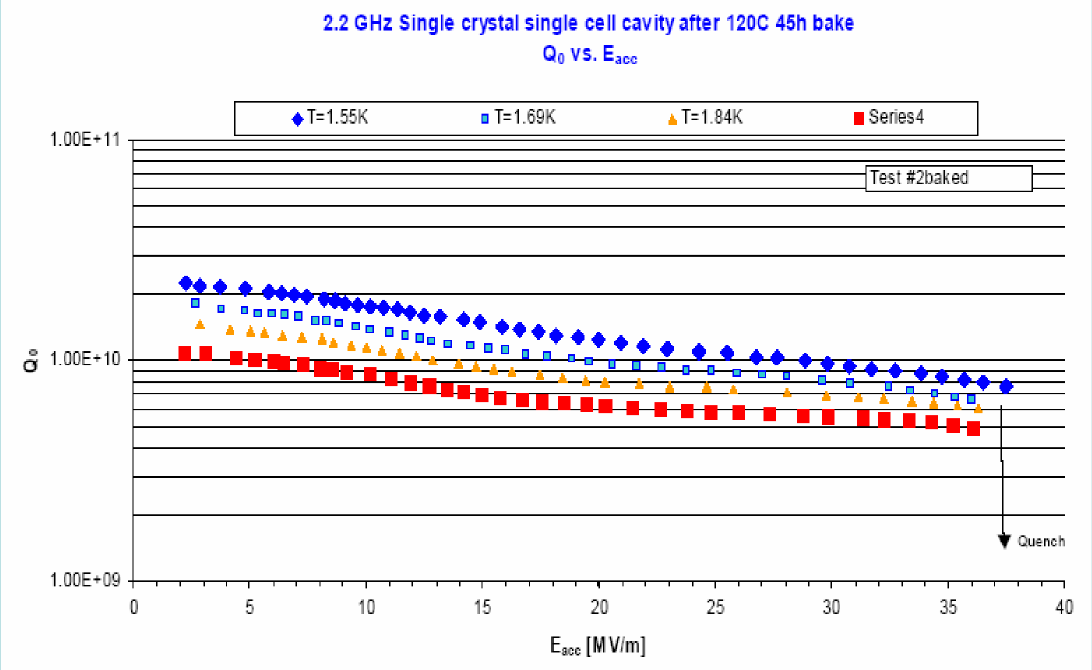
Single Crystal BCP: Smoother surface

Jlab R&D





Single Crystal Niobium Cavity Test Result (March 05)



RMS: 1247 nm fine grain BCP

27 nm single crystal BCP

251 nm fine grain ep

3.9 GHz Accelerating Cavity R&D

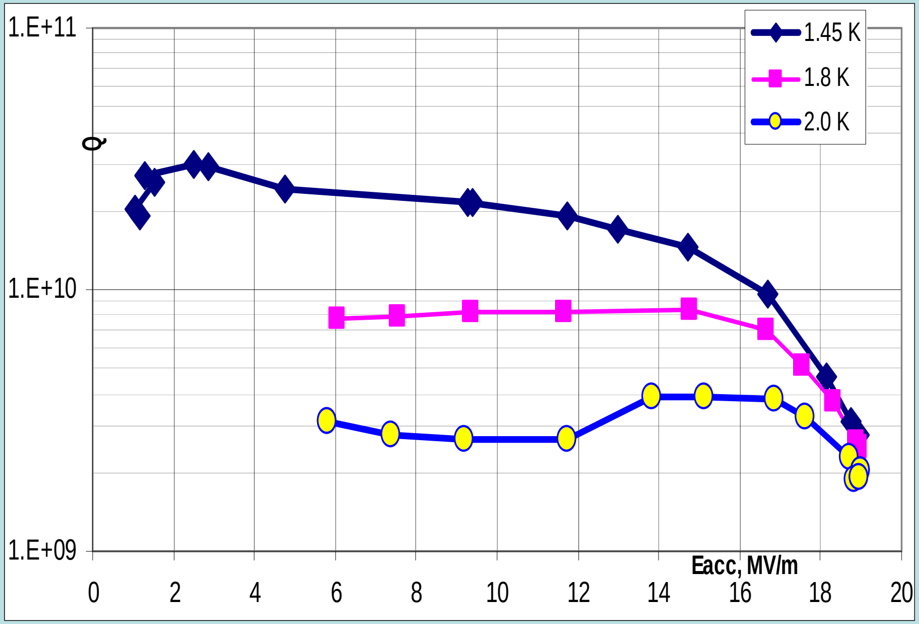
Test result of the 3-cell cavity

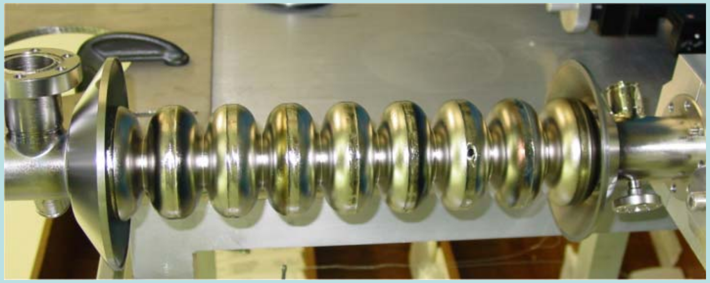
- Final cavity preparation done at FNAL (BCP,HPWR)
- Residual resistance *R_res ~ 6 nΩ*
- Achieved: *H_peak = 103 mT, E_acc = 19 MV/m*

(Goal: H_{peak}= 68 mT, Eacc=14 MV/m)

Magnetic field is likely limited by thermal breakdown

- No Field Emission
- *Q ~ 8*10 ^{9} at E_acc =15 MV/m*
- Maximum accelerating field not depend on Temp





First 9-cell cavity built at FNAL (goal: +4 at 2005)

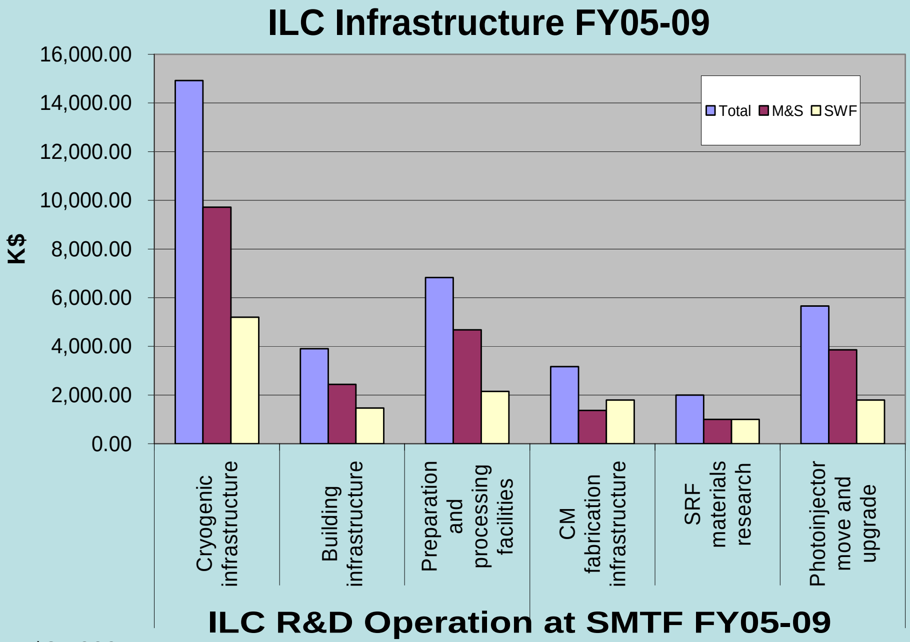
9-cell/3.9GHz: → *E_{acc}= 21 MV/m*

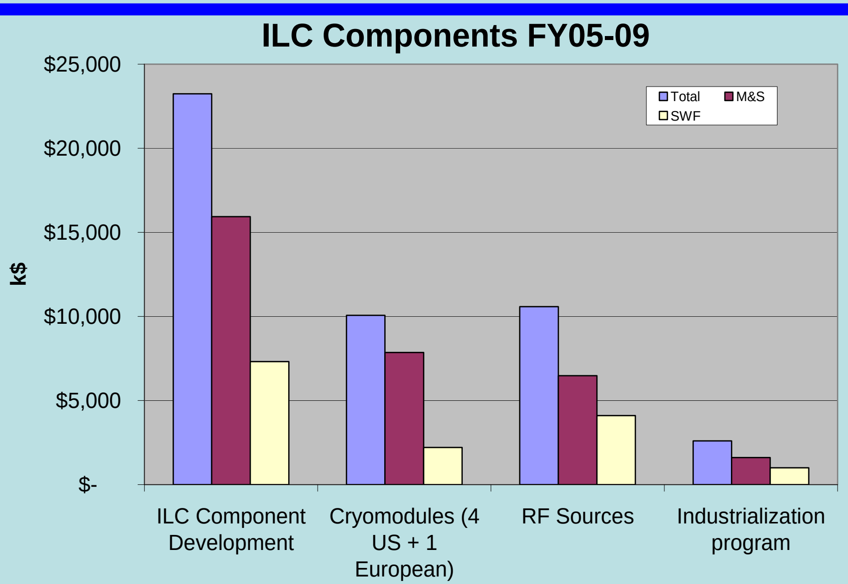
TESLA: → *E_{acc}= 24 MV/m*

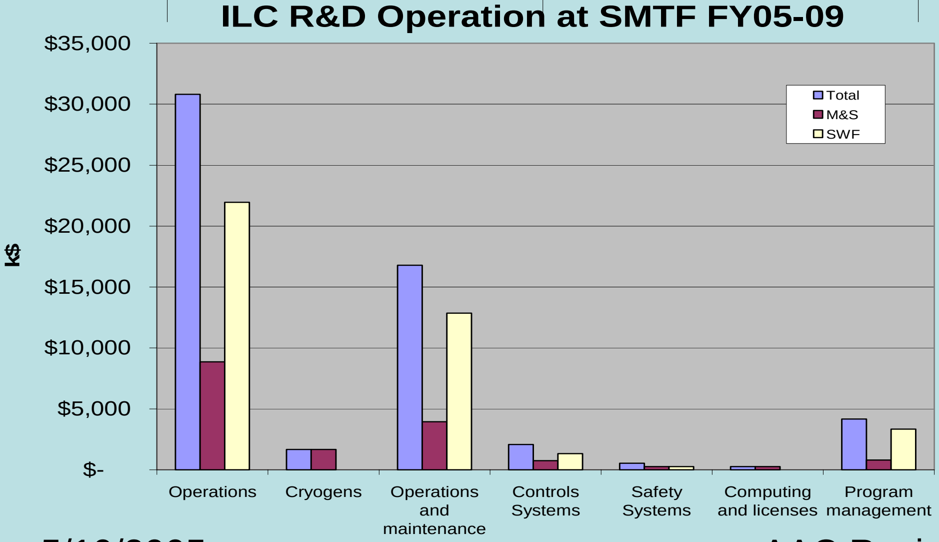
3rd Harmonic Accelerating Cavity: ILC Bunch Compressor

3rd Harmonic Deflecting Cavity: ILC Crab cavity at IR

Resources Overview







Total budget request for ILC is ~$90 M.

M&S: ~48 M

SWF: ~42 M

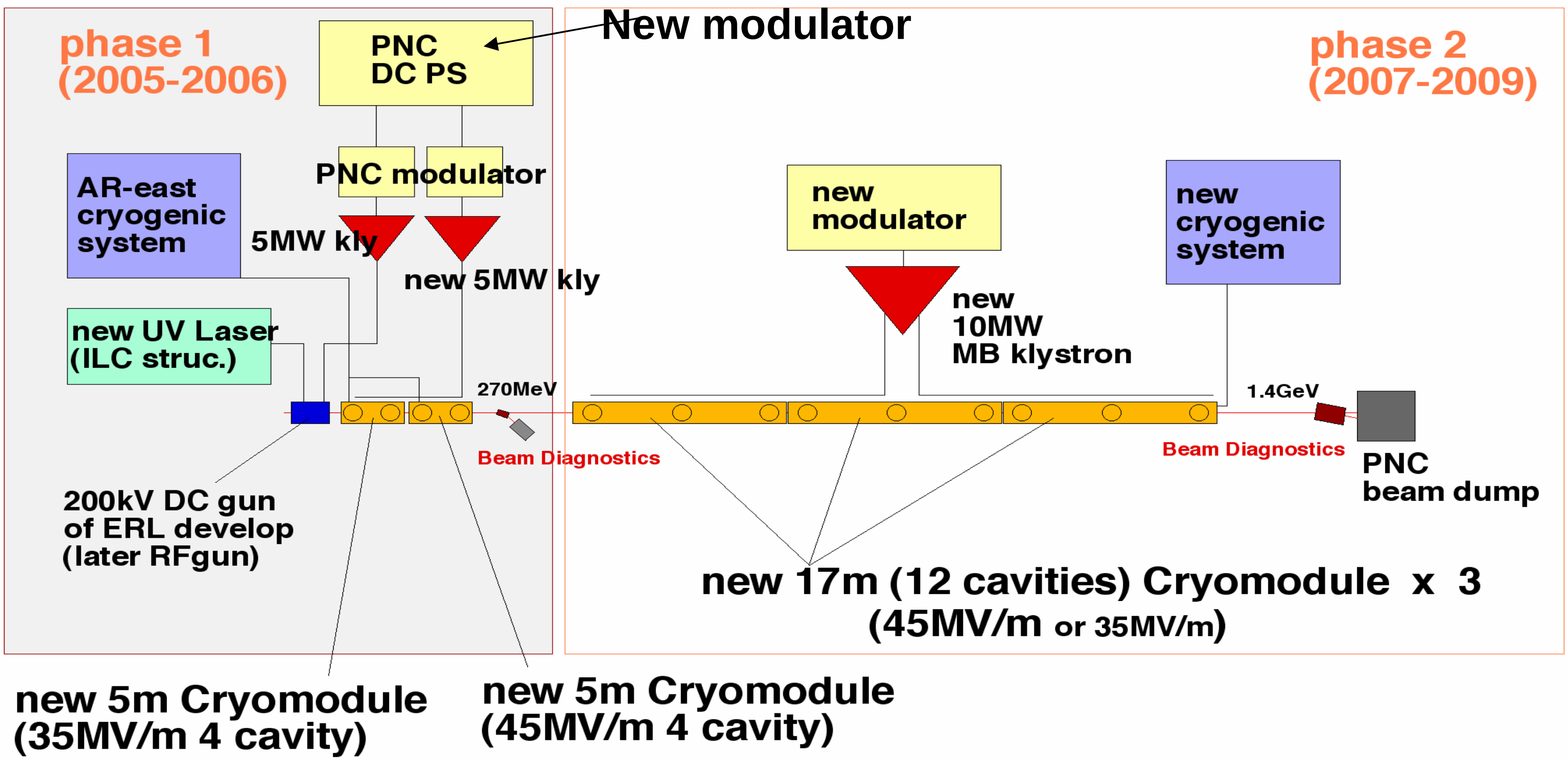
This is for the duration of FY05-09.

ILC Deliverables

- Priority 1
  - Cavity technology to routinely achieve ≥35 MV/m and Q ~0.5-1e10.
  - ILC Cryomodule with final design
  - Fully tested basic building blocks of the Main ILC Linac. Evaluate the reliability issues. Finalize design choices in collaboration with GDE.
- Priority 2
  - RF controls and LLRF System for ILC
  - Instrumentation Development
  - Enhance interaction with industry and Cavity & Cryomodule Technology transfer to Industry.
- Priority 3
  - Production Testing: US Manufacturing development and testing center
  - High gradient cavity development
    - Reentrant and Low Loss Cavity
    - Single Crystal Cavity
  - 3.9 GHz accelerating for bunch compressor

ILC SCRF R&D Plan at KEK

Plan of Superconducting RF Test Facility (STF)



V1.1 Hitoshi Hayano, 12/08/2004

Summary